# Assessment Methods for Restrictions in Manual Dexterity: Suitability for Exposure to the Cold

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## *ABSTRACT*

*Manual work (e.g. operating machinery or installation and assembly tasks) are of great importance in civilian everyday life and military standard duties. However, numerous circumstances (carrying loads, exposure to cold etc.) may lead to restrictions in manual dexterity or coordination and reduction in hand grip strength. Thus, suitable assessment methods are needed to quantify such effects. A steadiness test to quantify hand-steadiness (Leyk et al. 2006) and a method to measure hand-grip strength (Leyk et al. 2007) have been successfully deployed to assess changes in hand tremor as well as in force-time courses of hand-grip strength before and after stretcher carriage (Leyk et al. 2006). In this study, both methods were tested for their suitability to detect changes in hand tremor and manual work performance while the hands were exposed to cold. Additionally, a screw/bolt skill test was modified to represent common construction and assembly tasks.*

*16 male subjects were exposed to cold (1 h) in a climate chamber (-5 °C, $v_{air}$ <1 m/s). Subjects were moderately physically active and adequate thermal insulation of the body (approx. 2 clo) was provided. Before and during cold exposure, the screw/bolt skill test and the hand-steadiness test were administered and measurements of hand-grip strength were taken. The study included two different conditions (bare hands all the time vs. gloves, removed after the screw/bolt skill test).*

*Due to mechanical and haptical encumbrance, time to completion (Mean ± SD) was significantly longer with gloved hands compared to bare, cold hands in the screw/bolt skill test (220±52 s vs. 134±25 s; p<0.001). This test appears suitable to determine the extent of encumbrance caused by gloves.*

*The hand-steadiness test showed an increased number of wall contacts and duration time of wall contacts between the warm hands (controls) and exposed cold hands (both conditions). However, changes were not statistically significant, because adequate thermal insulation of the body prevented cold induced tremor or shivering which would have affected hand-steadiness. Thermal insulation of the forearm muscles also prevented the loss of hand-grip strength in cold hands.*

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14. ABSTRACT

**Manual work (e.g. operating machinery or installation and assembly tasks) are of great importance in civilian everyday life and military standard duties. However, numerous circumstances (carrying loads, exposure to cold etc.) may lead to restrictions in manual dexterity or coordination and reduction in hand grip strength. Thus, suitable assessment methods are needed to quantify such effects. A steadiness test to quantify hand-steadiness (Leyk et al. 2006) and a method to measure hand-grip strength (Leyk et al. 2007) have been successfully deployed to assess changes in hand tremor as well as in force-time courses of hand-grip strength before and after stretcher carriage (Leyk et al. 2006). In this study, both methods were tested for their suitability to detect changes in hand tremor and manual work performance while the hands were exposed to cold. Additionally, a screw/bolt skill test was modified to represent common construction and assembly tasks.**

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# 1.0 INTRODUCTION

Manual work (e. g. operating machinery or installation and assembly tasks) are of great importance in civilian everyday life and military standard duties. However, numerous demanding situations (carrying loads, repairing of wheel and tracked vehicles, etc.) may lead to restrictions in manual dexterity or coordination and to reduction in hand grip strength.

Thus, suitable assessment methods are needed to quantify such effects, for example to devise ergonomic countermeasures. A steadiness test to quantify hand-steadiness (Leyk et al. 2006) and a method to measure hand-grip strength (Leyk et al. 2007) have been successfully deployed under moderate climatic conditions to assess changes in hand tremor as well as in force-time courses of hand-grip strength before and after stretcher carriage (Leyk et al. 2006).

During cold exposure restrictions in manual dexterity are also to be expected. They may result either from cold hands or are caused by wearing gloves, which restrict the execution of delicate manual tasks. Therefore methods are also needed, in order to quantify the restrictions under these conditions.

In this study, both methods, the hand-steadiness test and the measurement of hand-grip strength, were tested for their suitability to detect changes in hand tremor and manual work performance while the hands were exposed to cold. Additionally, a screw/bolt skill test (Glitz et al. 1996) was modified, to represent common construction and assembly tasks with or without gloves during cold exposure.

# 2.0 METHODS

## 2.1 Subjects and Study Design

A group of 16 healthy male volunteers, all acclimatized to cold conditions, took part in the study. All volunteers were informed about aim, scope and risks of the study and gave their written consent. Prior to the tests each person underwent medical examination, including measures to obtain anthropometry and body composition. Subjects were familiarized with the tests procedures and baseline measurements of all tests (screw/bolt skill test, hand-steadiness, hand-grip strength) were obtained under room temperature. Baseline measures of hand-steadiness and maximal grip strength were taken twice and pooled before their use as comparison for the statistical analysis. The study was approved by the Ethics Committee of the medical association of the federal state Rhineland-Palatinate, Germany.

**Table 1: Anthropometry of the 16 volunteers (Mean ± SD).**

| | |
|---|---|
| Age (year) | 22.2 ± 4.8 |
| Weight (kg) | 74.5 ± 8.5 |
| Height (cm) | 177.9 ± 6.4 |
| Body Mass Index (kg/m$^2$) | 23.5 ± 1.9 |
| Body-Fat (%) | 19.2 ± 3.7 |

The volunteers were exposed to cold in a climatic chamber twice (-5 °C, $v_{air}$ <1 m/s). During each one-hour exposition, they were moderately physically active and adequate thermal insulation of the body (approx. 2 clo) was provided.

The study included two different conditions: “bare hands” (“B”) or wearing military five-finger gloves (“G”). Under both conditions, the screw/bolt skill test was conducted after minute 26. Gloves were removed after minute 43 and under both conditions the effects on manual coordination were assessed by means of the hand-steadiness device. Finally, maximal isometric hand-grip forces of both hands were also recorded under both conditions.

The military five-finger gloves are equipped with a three-layer laminate insert. The back of the gloves is made from five-colour camouflage fabric, the palm is goat leather. The thermal comfort range of the gloves had been described recently (Zimmermann et al. 2008).

**Figure 1: Military five-finger gloves.**

## 2.2 Heart Rate, Body Temperatures and Self-Perceived Thermal Sensations

Heart rate, mean body skin temperature according to Ramanathan (1964) and hand skin temperature (dominant hand: little finger) were measured continuously. Temperatures were supervised on-line to prevent cold induced injury. Tympanic membrane temperature was taken directly before and immediately after cold exposure.

Self-perceived thermal sensation ratings of the body [comfortable (0) - icy (6)] were ascertained at the beginning and in the end of cold exposure.

## 2.3 Manual Tests

### 2.3.1 Screw/Bolt Skill Test

Effects on manual coordination were assessed by means of a screw/bolt skill test (Glitz et al. 1996), which was modified to represent common construction and assembly tasks: In a standing position, both hands were used to fasten five nuts (galvanized steel, DIN 934) onto five corresponding bolts (galvanized steel;

length: 50 mm; core diameter: 10 mm; M 10 x 50; DIN 933). All bolts had to be inserted into bores on a wooden board (thickness: 16 mm) before tightening the nuts. Measurement criterion was time to completion of the task.

**Figure 2: Screw/bolt skill test.**

### 2.3.2 Hand-Steadiness Test

Effects on manual coordination were assessed by means of a previously described (Leyk et al. 2006) hand-steadiness test (Steadiness panel, ZInstSanBw KOB, Koblenz, Germany). Using their dominant hand, the sitting subjects had to hold a pencil (diameter: 1 cm) with a metal pin (diameter: 2 mm) as steady as possible in a bore of 3.8 mm diameter. About 5-10 mm of the pin´s length had to remain inserted into the bore. During the test period of 32 s the number of wall contacts and the duration time of wall contacts were measured. No hand or arm support was permitted.

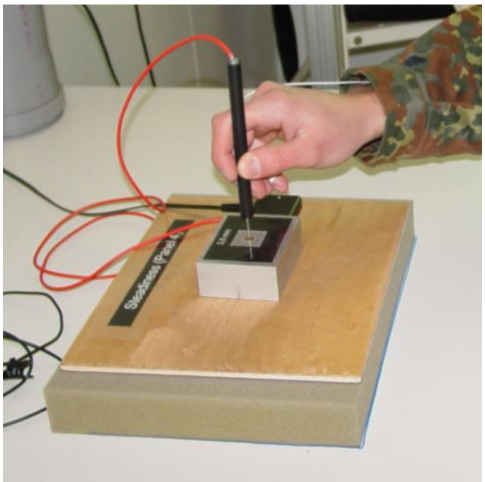

**Figure 3: Hand-steadiness test.**

### 2.3.3 Maximal Isometric Hand-Grip Strength

Maximal isometric hand-grip strength was recorded over 15 s using a handheld grip ergometer (Leyk et al. 2007). Device dimensions are shown in Fig. 4. Force was measured by a strain gauge sensor (K-2565, Lorenz Messtechnik Ltd., Alfdorf, Germany; measuring range 1500 N, accuracy: 0.1 %) at a sampling rate of 50 Hz, yielding 750 data points. During measurement, upper arm and forearm were supported in a way that a 90° flexion of the elbow joint was achieved without additional effort. Maximal isometric hand grip strength was derived from the 15 s force-time courses. After correction for obvious outliers the maximum value of all 750 data points was defined as maximum handgrip force for each test.

**Figure 4: Measurement of hand-grip strength.**

## 2.4 Statistical Analysis

Statistical analyses were performed using SPSS™ 14.0.1 and STATISTICA™ 8.0. Data were analysed by one-way ANOVA or two-way ANOVA (factors: “climate” and “hand clothing”, respectively). The Newman-Keuls-Test was used for post-hoc-comparisons. Differences were regarded as statistically significant for $p<0.05$. Unless otherwise noted, data are given as means (M) and standard deviation (SD) in tables and text or means (M) and standard error (SE) in figures.

# 3.0 RESULTS

## 3.1 Heart Rate, Body Temperatures and Self-Perceived Thermal Sensations

Mean heart rates (M±SD) were similar under both conditions ($p>0.05$): 84±9 b/min (“B”) and 85±8 b/min (“G”).

Neither core nor mean body skin temperatures showed statistical differences between the two conditions. Under both conditions, significant reductions of tympanic membrane temperature and mean body skin temperature could be observed between begin and end of cold exposure: Tympanic membrane temperature (M±SD) decreased from 37.0±0.5 °C to 35.9±0.6 °C ($p<0.001$) under “B” and from 36.7±0.4 °C to 35.9±0.7 °C ($p<0.001$) under condition “G”. Mean body skin temperature (M±SD) fell from 33.8±0.4 °C to 32.3±0.6 °C (“B”, $p<0.001$) and from 33.8±0.7 °C to 32.4±0.9 °C (“G”, $p<0.001$).

Figure 5 presents the skin temperature of the little finger from the dominant hand. Temperature fell below 15 °C in minute 8 under condition “B” and in minute 43 under condition “G”. After removing the gloves (“G”), the temperature rapidly decreased below 10 °C and reached the level of condition “B”. In the end the temperatures (M±SD) reached comparable levels 7.3±1.8 °C (“B”) and 7.3±2.0 °C (“G”).

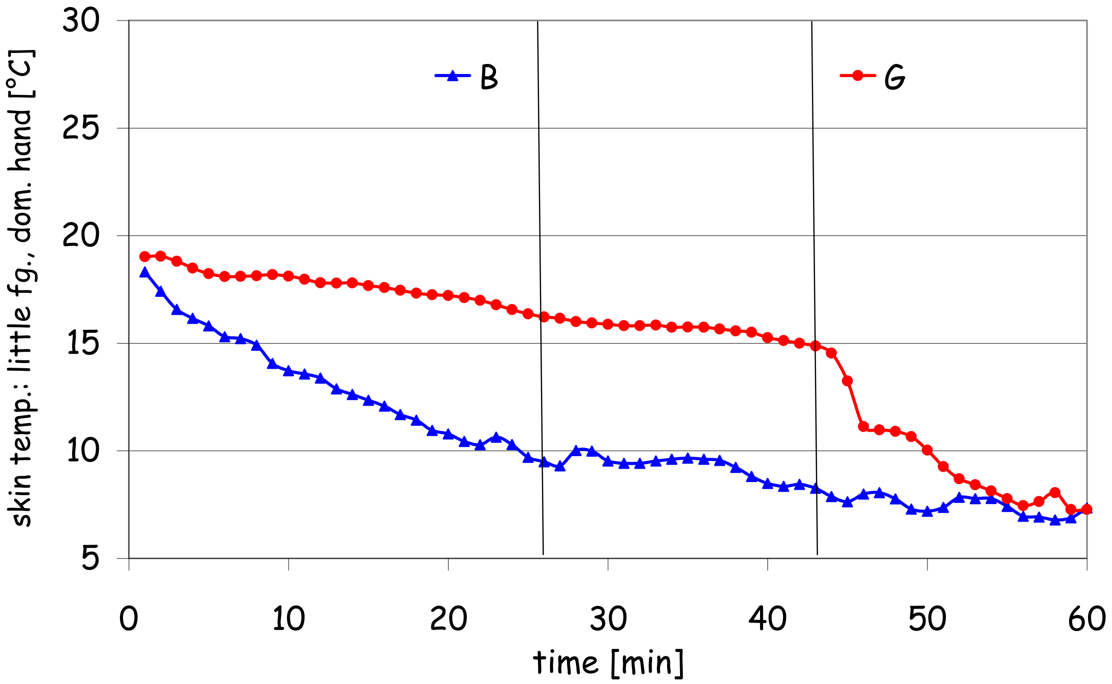


**Figure 5: Skin temperatures of the little finger of the dominant hand (values are means, n=16) with bare hands ("B") or wearing thick gloves for about ¾ of the time ("G"). The screw/bolt skill test was performed after minute 26. Gloves were removed after minute 43 and the hand-steadiness test was administered. Finally, maximal isometric hand-grip force of the dominant hand was recorded.**

Self-perceived thermal sensation of the body remained steady and at a comfortable level (between 0 and 1) under both conditions ($p>0.05$): Under condition "B" (M±SD) mean scores of 0.1±0.2 at the beginning and 0.5±0.7 in the end of cold exposure were recorded. Under condition "G" the ratings were 0.1±0.2 at the beginning and 0.6±0.8 in the end.

## 3.2 Manual Tests

### 3.2.1 Screw/Bolt Skill Test

In the screw/bolt skill test time to completion (M±SD) with bare hands ("B") was 123±26 s in the control and 134±25 s in the cold ($p>0.05$). With gloves ("G") there was a statistically significant increment ($p<0.001$): Time to completion was 187±64 s in the control and 220±52 s in the cold ($p<0.01$).

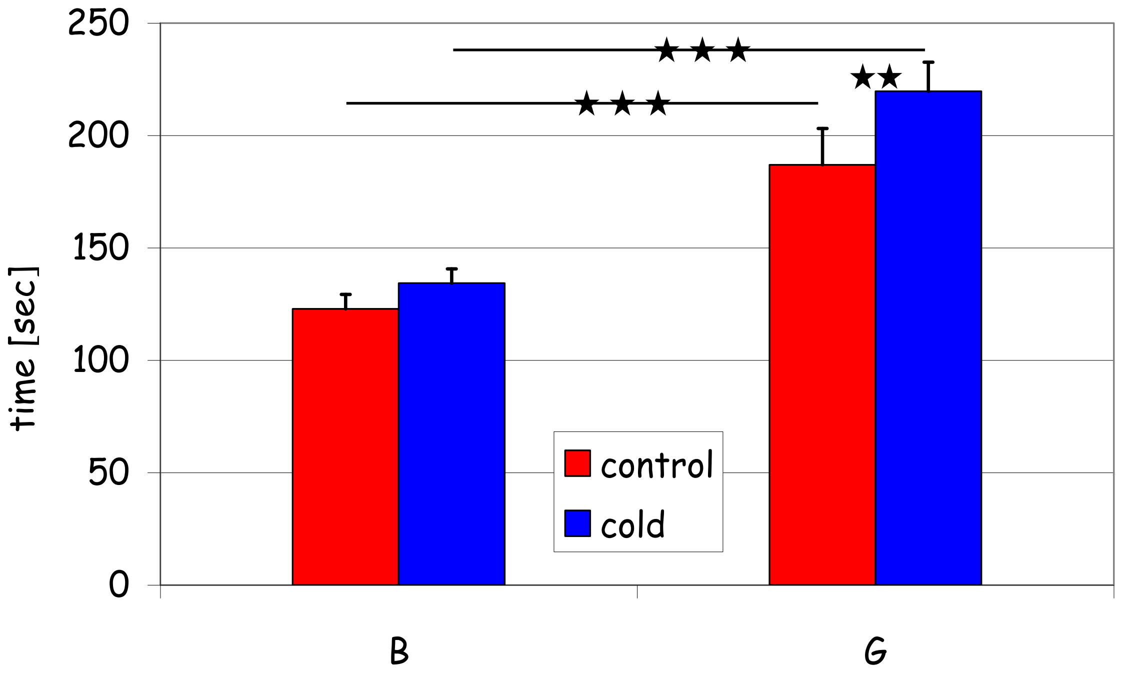


**Figure 6: Times to completion (values are means±SE, n=16) in the screw/bolt skill test with bare hands (“B”) or gloves (“G”) under control or cold conditions. With bare hands (“B”) there was no statistically significant difference (M±SD) between control (123±26 s) and cold (134±25 s). With gloves (“G”) there was a statistically significant increment compared with “B” ($p<0.001$): Time to completion was 187±64 s in the control and 220±52 s in the cold ($p<0.01$).**

### 3.2.2 Hand-Steadiness Test

The hand-steadiness test showed an increased number of wall contacts and duration time of wall contacts between the warm hands (controls) and exposed cold hands (conditions “B” and “G”). However, changes were not statistically significant ($p>0.05$).

**Table 2: Number of wall contacts and duration time of wall contacts in the hand-steadiness test of the 16 volunteers (M±SD); “B”: bare hands during the whole time; “G”: gloves were removed before the test. No statistically significant differences were found ($p>0.05$).**

| | Controls | B (bare hands) | G (gloves removed) |
|---|---|---|---|
| wall contacts (n) | 14.6 ± 11.7 | 25.4 ± 25.5 | 24.4 ± 26.0 |
| contact duration (s) | 0.72 ± 0.57 | 2,85 ± 3.35 | 2,53 ± 4.23 |

### 3.2.3 Maximal Isometric Hand-Grip Strength

Maximal isometric hand-grip force of the dominant hand showed minor differences: Hand-grip force of dominant hand was 500±83 N (M±SD) in the controls and remained at this level with 500±79 N (“B”) and 526±83 N (“G”) in the end of cold exposure. Although this last result led to statistically significant differences between the two conditions in the cold ($p<0.05$), the absolute difference was less than 6 % between „B” and “G” in the end of cold exposure. For the non-dominant hand no statistically significant differences were found.

**Table 3: Maximal isometric hand-grip force of the 16 volunteers (M±SD). Hand-grip force of the dominant hand was the same in the controls and under “B” (bare hands during the whole time). There was a statistically significant difference between “B” and “G” (gloves were removed after minute 43). Hand-grip force of the non-dominant hand showed less differences.**

| | Controls | B (bare hands) | G (gloves removed) |
|---|---|---|---|
| dominant hand (N) | 500 ± 83 | 500 ± 79* | 526 ± 83* |
| non-dom. hand (N) | 478 ± 76 | 473 ± 93 | 490 ± 78 |

* p<0.05, statistically significant between B and G

## 4.0 DISCUSSION

In spite of the low metabolic rates – illustrated by the heart rates – the thermal insulation provided by the clothing was sufficient to maintain the thermal comfort of the body.

In the **screw/bolt skill test** restrictions in manual dexterity due to mechanical and haptical encumbrance of the gloves were significant. Time to completion was longer with gloved hands during the controls and even in the cold compared to bare hands. Thus, this test appears suitable to determine the extent of encumbrance caused by gloves. It remains unclear why there was a difference between times to completion in the cold compared to the control. The temperature of the gloved hands could not be the reason because of the unrestricted performance of the much colder bare hands.

The **hand-steadiness test** showed an increased number of wall contacts with cold hands and duration time of wall contacts between the warm hands in the controls and under both cold exposed conditions. However, changes were not statistically significant. This result demonstrates the methodical difficulties in assessing the hands during cold exposure in an isolated manner without taking into account the heat content of the whole body. In our study, there was an adequate thermal insulation of the body, so that core and mean body skin temperature didn´t show any indications of hypothermia. This fact prevented cold induced tremor or shivering which would have affected hand-steadiness.

The influence of the body heat content (Brajkovic et al. 2001, Flouris et al. 2006) has been underestimated in many studies of manual dexterity. This fact, however, explains the difficulties to define a limit for the occurrence of manual restrictions during cold exposure (Glitz et al. 2007, Glitz et al. 2008). In literature, 15 °C for the local skin temperature of the hand is mentioned (Heus et al. 1995). In our study, skin temperature of the little finger reached the 15 °C limit even with gloves and the remaining benefit of the thermal insulation of the hands was rapidly lost when gloves were removed. Despite of decreasing hand skin temperatures, the effects of cold hands on manual dexterity or coordination were not as pronounced as expected by such low local skin temperatures. This could be attributed to heat content of the whole body.

The **measurement of maximal isometric hand-grip strength** took place at the end of cold exposure. At this time, differences in skin temperature of the fingers were negligible between the two conditions and had reached their lowest levels. However, baseline maximal isometric strength was reached or exceeded even slightly, but kept in the range of biological fluctuations. The reason was the thermal insulation of the forearm, which kept the muscles warm and prevented the loss of hand-grip strength in cold hands.

To estimate the suitability of hand-steadiness test and the measurement of hand-grip strength to detect changes in hand tremor and manual work performance while the hands were exposed to the cold it is necessary to take the whole body content (i. e. core and mean body skin temperature) in consideration, too. The isolated testing of cold hands is not sufficient while there is no great heat loss of core and muscle, and isolated hand temperature measurements are not a good predictor of manual performance. The additional screw/bolt skill test appears suitable to determine the extent of encumbrance caused by gloves.

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